ITR: Optical Control in Semiconductors for Spintronics and Quantum Information Processing (Grant No. DMR- 0325474)

J. Kono, H. Munekata, D. H. Reitze, L. J. Sham & C. J. Stanton
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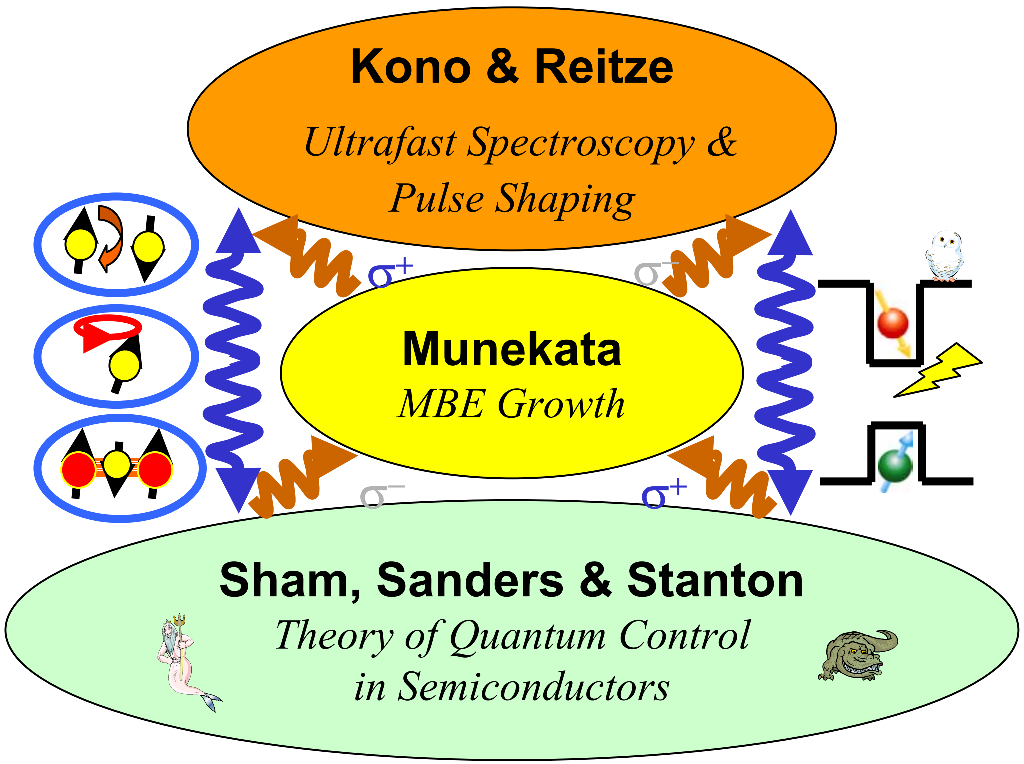
Objective:
To develop novel **ultrafast optical methods** in semiconductors for applications in *spintronics*, or *quantum information science* through **coherent** light-matter interactions involving **ferromagnetism, band structures, lattice vibrations,** and **excitons.**



Approach:
- Broad, international, interdisciplinary team involving physics, electrical engineering and material science from U.S. and Japan
- Combines MBE growth with ultrafast experimental techniques and a strong theory component.

The goal of this ITR program is to develop ultrafast optical methods for controlling electronic, magnetic, vibrational, and optical properties of semiconductors for fast information processing. Successful manipulation of quantum states and processes in solids --- nano-engineered semiconductor structures in particular --- will be a necessary breakthrough for implementing the emerging technologies of 'spintronics' and quantum information science. Optical control, as opposed to electrical control, has the advantage of performing quantum control on femtosecond (less than one trillionth a second) time scales, which we are exploring in the following four specific contexts: 1) Optical control of ferromagnetism in magnetic III-V semiconductors; 2) optical control of band structure using the dynamic Franz-Keldysh effect; 3) optical control of electric fields in GaN/InGaN strain superlattices; 4) optical control of excitons in coupled quantum wells.

We have formed a unique, interdisciplinary and international team to conduct this innovative research, consisting of three experimentalists and two theorists. A key feature is our combined expertise in molecular-beam epitaxy, optical and terahertz spectroscopy, ultrafast optical phenomena and pulse shaping, many-body theory, and theory of electronic, optical and magnetic properties. Each investigator could not separately accomplish all of the objectives of this program alone.

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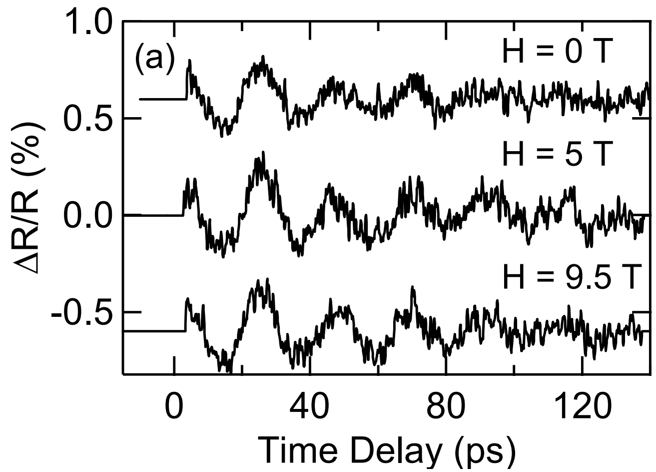
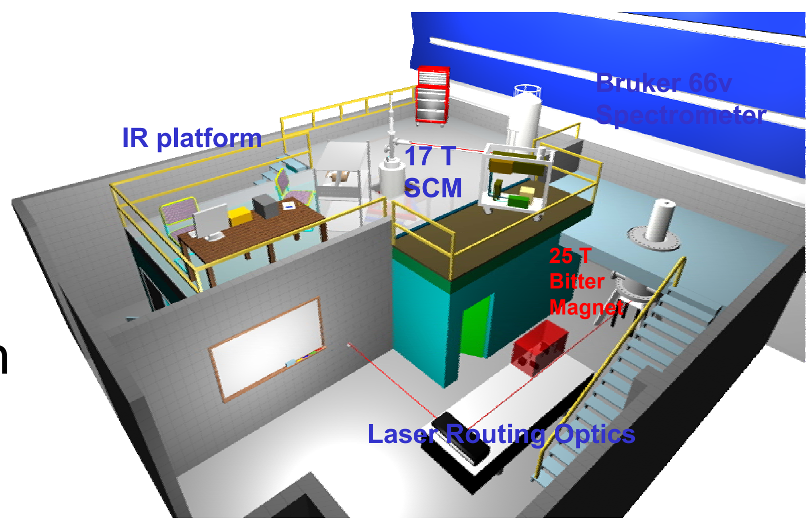
Significant results:

- First demonstration of *ultrafast manipulation* of *ferromagnetism*.
- Proposed *optical RKKY mechanism* for control of spin.
- Calculations and observations of *coherent phonon* generation in *magnetic films*.
- Development of *ultrafast optical* capabilities at high magnetic fields at the NHMFL for future studies.



Oscillations in the magneto-reflectivity are not sensitive to the magnetic field indicating that *coherent phonons* are responsible in agreement with calculations.



Schematic diagram of ultrafast optics lab being built at the NHMFL. This unique facility will enable studies of materials with 100 fs optical pulses and 30 T magnetic fields important for future studies

1) We have demonstrated that optical excitation of ferromagnetic semiconductors such as InMnAs and GaMnAs can change their basic magnetic properties. This paves a natural way to optically control magnetism in semiconductors – important for information storage and processing.
2) We have proposed a new mechanism for inducing interactions between electronic spins confined in adjacent quantum dots. The mechanism does not rely on the creatin of 'real' carriers and thus very fast – ideal for ultrafast information processing using spins.
3) We have calculated and experimentally demonstrated that ultrashort optical pulses can generate coherent phonon wavepackets that propagate into the semiconductor crystal with a well-defined phase and amplitude. This can be useful for manipulating magnetism vibrationally.
4) We are currently developing a unique optics facility at the National High Magnetic Field Laboratory in Tallahassee, which will be used for studying ultrafast quantum coherent phenomena in solids in high magnetic fields. To our knowledge, this will be the first facility in the world which will combine 30 T fields with 100 fs laser pulses.

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Education & outreach:

- Graduate students: Jigang Wang (Rice), Xiaoming Wang (UF), Lukasz Cywinski (UCSD)
- Post-docs: Giti Khodaparast (Rice), Young-Dahl Jho (UF), Gary Sanders (UF)
- *"Physics is Phun"* show at the Florida Natural History Museum's *Sensational Science Day*
- Participated in *National Society of Black Physicists Conference*

Undergraduate Physics student Layla Boosheri with Chris Stanton demonstrate the effects of pressure on "peeps" to elementary school students.

Dwayne Browne listens to an explanation of quantum computing and entanglement by Dave Reitze.

We are involving graduate students and post-docs at the participating institutes in frontier projects in nanoscience and quantum information science to produce quantum scientists and engineers with a wide and strong background in spectroscopy, optics, photonics, solid state theory, many-body theory, and quantum information theory. New courses on nanotechnology and quantum information science are being planned in the Applied Physics curricula at Rice University, the University of Florida, and the University of California at San Diego. Chris Stanton participated in the “Physics is Phun” show at the Florida Natural History Museum’s Sensational Science Day and led undergraduate physics students to demonstrate the effects of pressure on “peeps” to elementary school students. Dave Reitze attended the National Society of Black Physicists Conference and spoke with a number of participants about quantum computing and entanglement.